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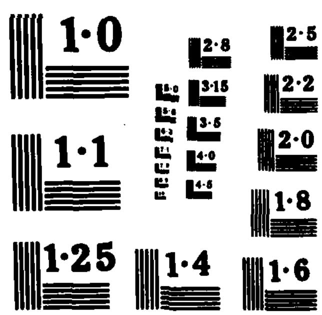
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This study assesses the effects of +Gz stress on operator task performance and workload. Subjects were presented a two-dimensional maze on a CRT, and were required to solve it as rapidly as possible while under G-stress at levels from +1Gz to +6Gz. The G-stress was provided by a human centrifuge. The effects of this stress were assessed by two techniques: (1) objective performance measures on the primary maze - solving task, and (2) subjective workload measures obtained using the Subjective Workload Assessment Technique (SWAT). It was found that while neither moderate (+3Gz) nor high (+5Gz and +6Gz) levels of G stress affected maze solving performance, the high G levels did significantly increase the subjective workload of the maze task.

Additional keywords: fighter aircraft; cockpits; pilots; workload; heat (physiology); physiological effects (A)

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PREFACE AND ACKNOWLEDGEMENTS

This work was performed under Project 7231, Task 17, Workunit 11 (Biomechanics of Air Force Operations: Effects of Mechanical Force on Air Force Personnel). The research was a joint effort between the Biodynamics and Bioengineering (BB) Division and the Human Engineering (HE) Division of the Air Force Aerospace Medical Research Laboratory (AFAMRL) and it was performed on the AFAMRL Dynamic Environment Simulator (DES), the human centrifuge.

The authors wish to thank Capt David Leupp who helped conceive this experiment and made significant contributions to the design of the experiment; Mr. Marvin Roark and Ms. Barbara O'Lear of the Raytheon Co., support contractors for the DES, who integrated the maze package on the DES computer facility and tailored the package to fit the protocol; MSgt Dan Bridges who helped develop the maze package at HE; Mr. Dave Ratino and the BBS electronics support group; Mr. John Frazier and Mr. Tom Shriver who controlled the experiment from the medical monitor room; Mr. Vance Skowronski who helped conduct various phases of the experiment; Capt Tom Jennings, MC, FS, and Dr. George Potor, Jr, M.D. the medical monitors; Dr. Clark Shingledecker and Mr. Gary Reid, AFAMRL/HEG, who reviewed and critiqued this work and report; SSgt Lloyd Tripp and SSgt Lora Howell who served as medical technicians and data recorders; and the entire DES crew, made up of both Air Force and Raytheon personnel.

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SECTION 1.0

INTRODUCTION

Technological advances in recent years have considerably increased the complexity of fighter aircraft cockpits. The number of individual parameters which the pilot must monitor and control has increased dramatically. A fundamental consequence of these advances has been to significantly alter the pilot's role from primarily a skilled manual control operator to that of an executive manager or decision maker.

Such alterations in the pilot's tasks have created an additional constraint for design engineers, namely pilot workload. As pilot workload increases, not only does he become fatigued more readily, but his performance begins to deteriorate. Excessive pilot workload can result in some piloting tasks not even being performed, with potential catastrophic consequences. Clearly, pilot workload is a crucial factor which must be addressed in the design of modern fighter aircraft.

Concurrent with the advances in aircraft avionics have been major advances in propulsion, aerodynamics and airframe materials. As a result, the modern fighter aircraft is capable of maneuvers with considerably higher G-levels and G-onset rates than those of its predecessors. The effects of G-forces will become even more severe with the next generation fighters which are expected to exceed the current G-capabilities.

Although the increased G-environment of modern fighter aircraft may appear to be independent of the pilot workload problem, it probably is not. First, in order to maintain an adequate field of vision and consciousness at higher G-levels, pilots must perform an M-1 or L-1 straining maneuver. This coordinated grunting and isometric muscular straining is an additional piloting task which requires some mental attention; thus the potential for increasing pilot workload. In addition, the G-induced reduced blood flow to the brain could impair higher level cognitive activity. This in turn would decrease the pilot's mental processing efficiency, making it more difficult for him to complete all necessary tasks adequately.

Pilot workload and pilot G-stress are two very important issues in the design of modern fighter aircraft. Although the physiological effects of G-stress have been studied for years by the aerospace medical community, little is known about the psychological effects associated with G-stress. Therefore, the objective of this effort was to investigate the impact of G-stress on pilot workload.

SECTION 2.0

BACKGROUND

There is an enormous amount of research that has been conducted on the effects of acceleration on humans. Most of it deals with the physiological effects; none of it specifically addresses the issue of G-stress on pilot workload. In fact, very little work has been done which addresses the effects of G-stress on the pilot's cognitive abilities. In Collyer's very thorough 1973 review (1), he cited several studies (2,3,4,5,6) which suggest increased G-stress has a negative effect on pilot's cognitive abilities. However, he concluded that knowledge in this area was quite incomplete and little has been done since then. Given the increased cognitive demands and increased G-stress being placed on the pilots of modern fighter aircraft, this area demands thorough investigation.

Similarly, there has been a plethora of research conducted in the general area of assessing operator workload. In a comprehensive review of the workload literature, including over 400 references, Wierwille and Williges (7) identified twenty-eight specific techniques for assessing operator workload. In the same paper, they also presented a method for selecting the most appropriate technique for a given context. Following their guidelines, it was decided to employ two alternative techniques: (1) an *objective measure of performance* (the specific task selected was 2-dimensional maze solving); and (2) a subjective measure of workload (the specific technique being the Subjective Workload Assessment Technique). Each of these techniques will be discussed in detail.

To be consistent with the referenced literature, the generic term of workload is used throughout this paper. However, the correct interpretation of workload as used here is that it is a combination of both internal and external workload, as well as processing capacity. Alternately, workload can be thought of as being inversely related to the amount of unused processing resources. That is, as the amount of available or unused processing resources decreases, the workload, by definition, has increased.

2.1 PERFORMANCE MEASUREMENT - MAZE SOLVING

The performance measurement technique used here was the maze-solving technique developed by Ward and her colleagues (10,11). Subjects were presented with an unfamiliar two-dimensional maze on a CRT and were required to move a dot through the maze from one side to the other as rapidly as possible (Fig. 1). The dot moved at a constant speed and direction, but subjects could change the direction with discrete control inputs of either up, down, left, or right. The score was defined as the ratio of the optimum solution time to the actual solution time.

This task was selected primarily because it required considerable cognitive resources, yet only minimal response resources. Thus, if an increase in G-stress resulted in a decrease in performance, it could not be attributed solely to a decrease in motor coordination. Rather, it would be primarily a consequence of a decrease in cognitive processing capabilities. Alternatively, if there was no change in performance, it could be the case that the maze-solving task did not provide sufficient task loading. This

would leave reserve processing resources to be expended under G-stress, and the measured performance would not change.

2.2 WORKLOAD ASSESSMENT - SWAT

In general, subjective workload assessment consists of requiring subjects to estimate the workload imposed by a given experimental manipulation via introspection. Although such a technique can be useful, it has been criticized for being easily biased and rather insensitive to changes in workload. Furthermore, it only produces a rank ordering of workload rather than a more desirable ratio or interval scale of workload.

Recently, however, Reid, Eggemeier, and their colleagues at the AFAMRL have developed a generic subjective technique called the Subjective Workload Assessment Technique or SWAT (12,13,14,15). It combines subjective ratings on three different scales, via the mathematical technique of conjoint measurement, to produce an interval scale of workload. It has been shown to be both a reliable and sensitive measure of workload. One significant advantage of SWAT is that it is a relatively simple and unobtrusive technique that could be easily implemented jointly with the maze-solving technique in the high G environment. Thus, SWAT was used in conjunction with the performance measure obtained via the maze-solving scores.

SECTION 3.0

METHODOLOGY

The objective of this study was to assess the effects of +Gz stress on pilot workload. It was conducted in three phases: Phase I - Static Training, Phase II - Dynamic Training, and Phase III - Data Collection. Pilot performance and workload were measured using primary task performance, via the two-dimensional maze-solving task, and subjective ratings via SWAT. AFAMRL's Dynamic Environment Simulator (DES) provided the G-stress. Special equipment included a modified ACES II or F-16 seat, side-arm controller, flight suit, gloves, anti-G suits, and Doppler temporal artery flow meter.

3.1 PHASE I - STATIC TRAINING

There were two tasks which were accomplished in the static training phase. Subjects performed a card sort to rank-order the subjective ratings that were used in Phase III, and they practiced solving two dimensional mazes similar to the ones which were used as the primary task in phase III. All work conducted in Phase I was in a normal +1 Gz environment. Each subject participated in four one-hour training sessions with each session occurring on a different day.

The purpose of the first session was to perform a card sort for the SWAT portion of Phase III. The subjects were provided with a deck of 27 cards placed in random order. Each card represented one of the possible combinations of three categories (time load, mental effort load, and psychological stress load) with each category at three different levels (low, medium, and high, Fig. 2). The subject's task was to sort these cards so that all 27 combinations were rank-ordered with respect to the degree of subjective workload imposed by each. These rank-orderings were then used to develop an interval scale of workload for evaluating the subjective ratings that were obtained in Phase III.

In the remaining three static training sessions, subjects practiced solving two-dimensional mazes. Figure 1 depicts a maze typical of those used throughout the experiment. All mazes consisted of the basic 10 x 10 grid as shown, but differed in the placement of the maze barriers. For each trial, a given maze was displayed on a CRT with a dot at the entrance of the maze. The subject's task was to solve the maze as rapidly as possible. The dot moved at a constant speed and the subject could change its direction (left, right, up, or down) by moving the trim tab button on a joystick controller in the appropriate direction.

The trial concluded as soon as the dot was successfully guided through the maze to the goal. The shortest possible solution time divided by the actual time required to complete the maze was used as the measure of performance, and this score, multiplied by 100, was displayed to the subject immediately after completion of each trial. Typical solution times were approximately one minute or less. If the subject failed to complete the maze within two minutes, the trial was terminated and a message was displayed indicating that the subject had run out of time. The displayed score was then computed as the ratio of the shortest possible solution time to actual solution of time, multiplied by the percent of the maze solved.

3.2 PHASE II - DYNAMIC TRAINING

The purpose of the dynamic training phase, which was conducted entirely on the DES, was to reduce the experimental variance in Phase III by permitting subjects to practice maze solving while under G-stress. Each subject practiced in two daily sessions of approximately one-half hour each. The specific G-profile (number of runs per session, duration of each run, etc.) was identical to those which were used in the data collection phase and are discussed in detail in the following paragraph. Different mazes were used in each of the three phases to prohibit learning effects due to subjects becoming familiar with any particular maze.

3.3 PHASE II - DATA COLLECTION

The data collection phase was also conducted on the DES. Each subject participated in five daily sessions of approximately one-half hour each; each session was comprised of eight trials. A trial was comprised of four parts.

(1) Positive Onset: Starting at a baseline level of +1.5 Gz, the subject's Gz level increased (or decreased) at the rate of .25 Gz/sec until the desired level of Gz for that trial was attained. Four levels of +Gz (1,3,5, and 6) were employed. The slow onset rate and the baseline level of 1.5 Gz were chosen to minimize the problems associated with vertigo.

(2) Test: Once the desired level of +Gz was attained, the subject was presented with a maze on the CRT and asked to solve it as rapidly as possible.

(3) Acceleration Offset: Two different rules for determining the time of acceleration offset were used in this study. For the first two subjects, offset started when the subject solved the maze or after two minutes at +Gz, whichever occurred first. Data from these two subjects indicated a moderate improvement in performance between +3 Gz and +5 Gz. It was believed that increased motivation to terminate the trial as quickly as possible at the higher +Gz level may have caused this performance improvement. To remove this possible confounding effect, the determination of acceleration offset time was changed. For the last two subjects, offset started after one minute at +Gz, regardless of maze completion.

For both offset rules, Gz was decreased (or increased if a 1 Gz trial) at the rate of .25 G/sec. until the baseline level of +1.5 Gz was attained.

(4) Rest: The subject then rested at the +1.5 Gz level for a minimum of one minute before initiating the next trial. However, this rest period could be extended for as long as desired by either the subject or the medical monitor. During this rest period, the subject was required to rate his perceived workload during the previous trial, using SWAT. After the SWAT rating was completed, the subject was informed of his maze-solving score.

Each daily session consisted of eight trials, with the first and second half of the session separated by a rest period of at least three minutes. Within each half of a session, the order of presentation of the +Gz levels followed an incomplete 5 x 4 (5 sessions x 4 trials per half-

session) Latin square. The eight different mazes used in Phase III were randomly assigned to each trial, with the following constraints: (1) each maze was used exactly once during a session, and (2) each maze was used once in combination with each +Gz level during the first four sessions of Phase III.

The first four daily sessions of Phase III were identical to that of Phase II. On the fifth day, each maze had the optimum solution path identified on the CRT. Thus the subject's only task was to maneuver the dot along the path. Comparisons of solution times between mazes with and without the solution path shown served as a direct measure of the cognitive effects of G-stress since the same motor coordination task was required for all conditions.

Heart rate (EKG), temporal artery blood flow (Doppler flow meter), and anti-G suit pressures were recorded for all trials in both Phases II and III (Fig. 3).

EFFECT OF $+G_Z$ ON SUBJECTIVE WORKLOAD ASSESSMENT

MEANS AND 95% CONFIDENCE INTERVALS

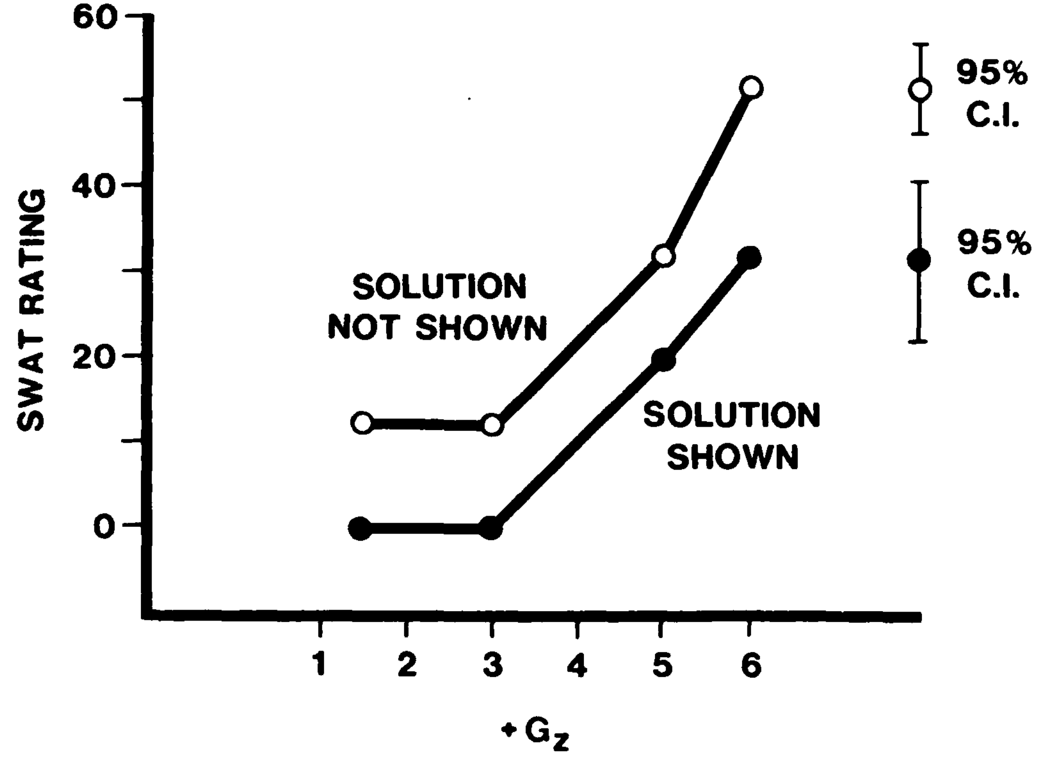

Figure 5

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EFFECT OF $+G_z$ ON MAZE-SOLVING PERFORMANCE

MEANS AND 95% CONFIDENCE INTERVALS

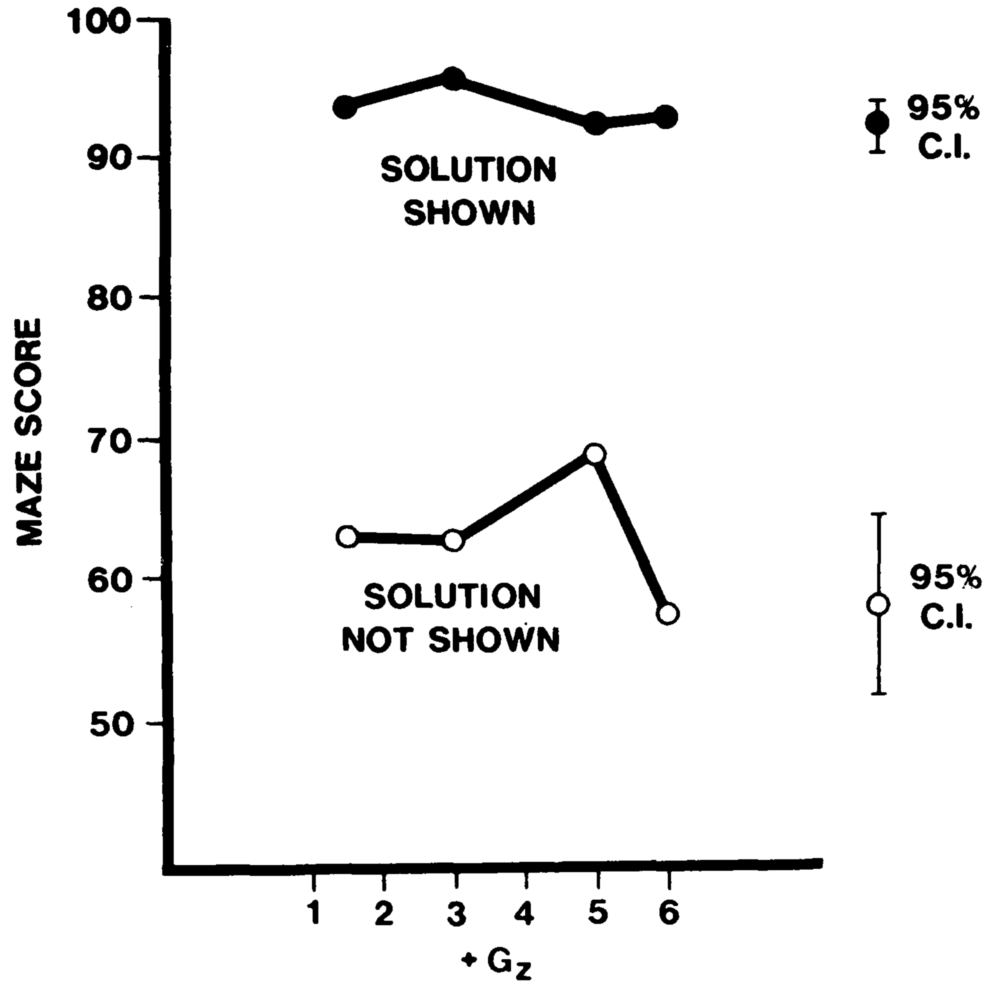


Figure 4

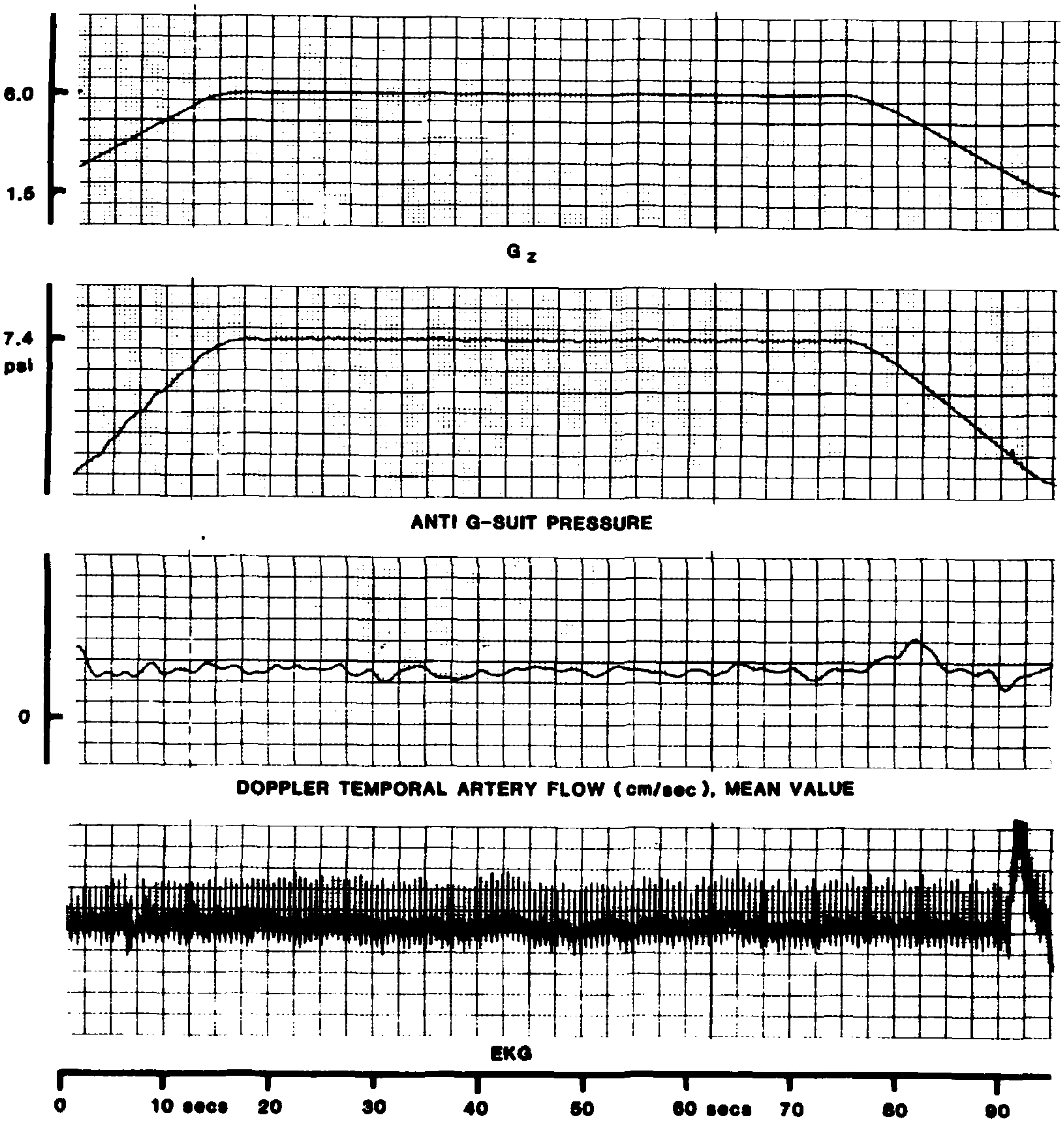
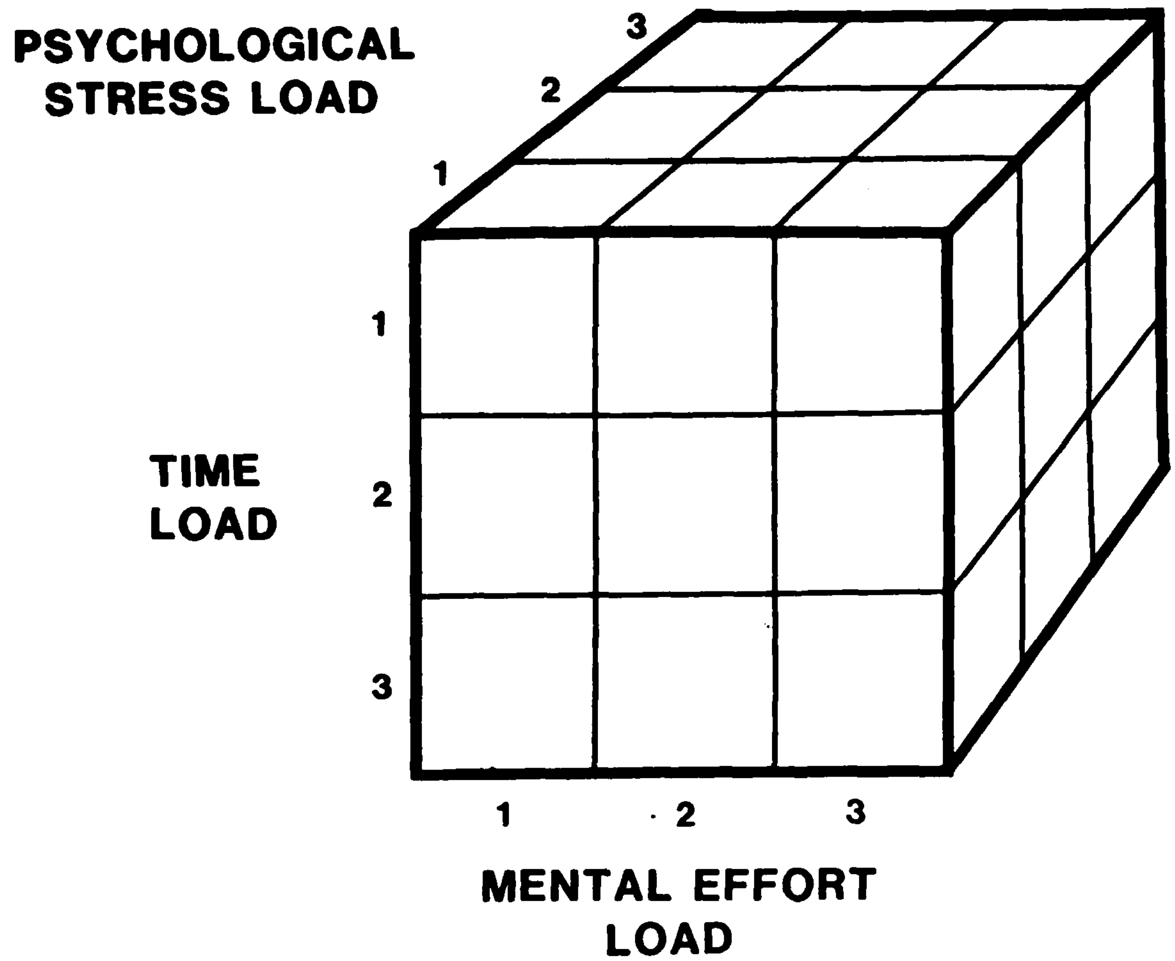


Fig. 3. TYPICAL STRIP CHART RECORDINGS FROM MAZE EXPERIMENT, 6 G RUN

Fig. 2 SWAT



PSYCHOLOGICAL
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MENTAL EFFORT
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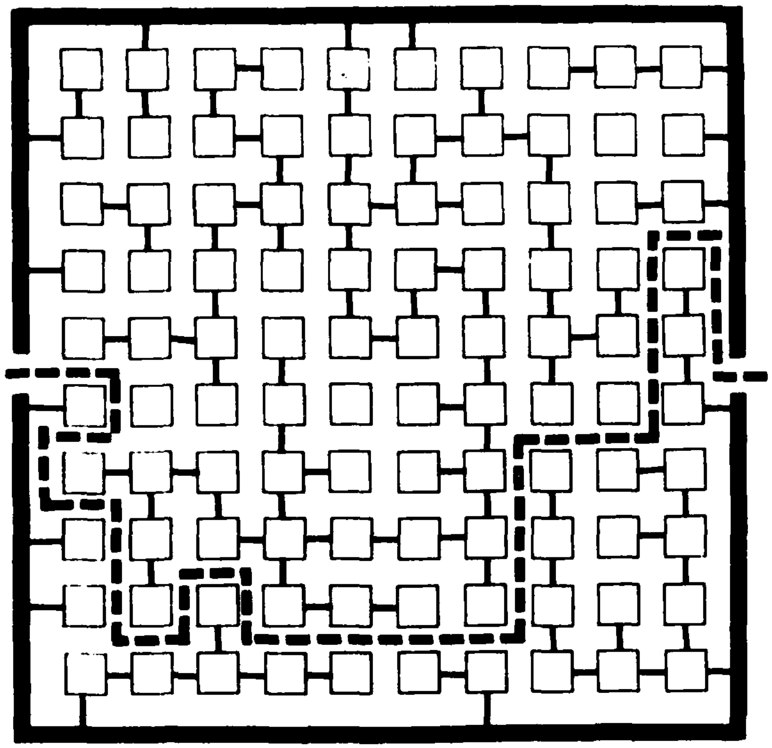

Fig. 1 TYPICAL 2-D MAZE WITH SOLUTION PATH (DASHED LINE)

TABLE 4. ANALYSIS OF VARIANCE RESULTS FOR SUBJECTIVE WORKLOAD ASSESSMENT

NO SOLUTION SHOWN

SOURCE	MS	df	F-STAT	PROB
Gz	11923	3	12.41	.01
Gz x Off	1073	3	1.12	-
Error = Gz x Subj(off)	961	6		
Maze	1360	7	2.65	.10
Maze x Off	874	7	1.70	-
Subj(off)	11264	2	21.96	.01
Error = Maze x Subj(off)	513	14		
Off	1763	1	.16	-
Error = Subj(off)	11264	2		
Gz x Maze	144	21	.82	-
Gz x Maze x Off	187	21	1.06	-
Gz x Subj (off)	961	6	5.43	.01
Error = Gz x Maze x Subj(off)	177	41		

SOLUTION PATH SHOWN

SOURCE	MS	df	F-STAT	PROB
Gz	2044	3	12.15	.01
Maze	159	7	.95	-
Subj	726	3	4.31	.05
Error: Residual	168	18		

TABLE 3. ANALYSIS OF VARIANCE RESULTS FOR MAZE-SOLVING PERFORMANCE

NO SOLUTION SHOWN

SOURCE	MS	df	F-STAT	PROB
Gz	675	3	1.94	-
Gz x Off	110	3	.32	-
Error = Gz x Subj(off)	348	6		
Maze	1550	7	4.35	.01
Maze x Off	1117	7	3.13	.05
Subj(off)	1243	2	3.48	.10
Error = Maze x Subj(off)	357	14		
Off	5	1	.00	-
Error = Maze x Off	1117	7		
Gz x Maze	342	21	1.16	-
Gz x Maze x Off	192	21	.66	-
Gz x Subj (off)	348	6	1.19	-
Error = Gz x Maze x Subj(off)	293	42		

SOLUTION PATH SHOWN

SOURCE	MS	df	F-STAT	PROB
Gz	17.1	3	2.84	.10
Maze	14.5	7	2.41	.10
Subj	30.3	3	5.02	.05
Error: Residual	6.0	18		

TABLE 2. SWAT RATINGS

		Gz LEVEL			
		1.5	3	5	6
MAZE 1	SUBJECT 1	0.0	0.0	1.70	58.01
	SUBJECT 2	62.30	13.53	58.01	65.96
	SUBJECT 3	0.0	11.60	44.61	59.66
	SUBJECT 4	0.0	0.0	29.56	51.71
MAZE 2	SUBJECT 1	0.0	0.0	13.53	1.70
	SUBJECT 2	11.83	0.0	56.30	58.01
	SUBJECT 3	11.60	11.60	41.16	41.16
	SUBJECT 4	20.84	0.0	29.56	51.71
MAZE 3	SUBJECT 1	0.0	11.83	1.70	13.53
	SUBJECT 2	87.75	87.75	13.53	100.00
	SUBJECT 3	30.10	11.60	41.16	63.31
	SUBJECT 4	0.0	20.84	50.40	50.40
MAZE 4	SUBJECT 1	0.0	0.0	1.70	1.70
	SUBJECT 2	0.0	1.70	58.01	65.96
	SUBJECT 3	11.60	11.60	41.16	81.81
	SUBJECT 4	0.0	0.0	29.56	29.56
MAZE 5	SUBJECT 1	0.0	11.83	1.70	1.70
	SUBJECT 2	11.83	11.83	58.01	64:26
	SUBJECT 3	11.60	30.10	59.66	81.81
	SUBJECT 4	0.0	20.84	29.56	72.55
MAZE 6	SUBJECT 1	0.0	0.0	1.70	1.70
	SUBJECT 2	0.0	0.0	11.83	13.53
	SUBJECT 3	0.0	11.60	41.16	81.81
	SUBJECT 4	0.0	0.0	50.40	72.55
MAZE 7	SUBJECT 1	0.0	0.0	1.70	1.70
	SUBJECT 2	0.0	13.53	46.18	100.00
	SUBJECT 3	11.60	11.60	11.60	41.16
	SUBJECT 4	0.0	11.60	29.56	51.71
MAZE 8	SUBJECT 1	11.83	11.83	1.70	13.53
	SUBJECT 2	58.01	0.0	58.01	95.70
	SUBJECT 3	30.10	30.10	59.66	91.04
	SUBJECT 4	29.79	39.33	41.16	91.04

TABLE 1. MAZE-SOLVING SCORES

		Gz LEVEL			
		1.5	3	5	6
MAZE 1	SUBJECT 1	64.73	78.38	78.06	14.98
	SUBJECT 2	22.47	48.21	16.85	67.29
	SUBJECT 3	83.11	69.95	58.46	52.14
	SUBJECT 4	82.66	78.51	77.68	77.71
MAZE 2	SUBJECT 1	87.17	83.93	93.71	73.84
	SUBJECT 2	83.04	83.33	88.83	85.78
	SUBJECT 3	88.81	95.18	59.01	84.20
	SUBJECT 4	53.05	82.95	68.42	72.42
MAZE 3	SUBJECT 1	57.77	37.45	77.54	20.60
	SUBJECT 2	14.98	29.96	82.27	29.96
	SUBJECT 3	23.37	74.39	81.88	66.52
	SUBJECT 4	81.71	38.49	77.92	67.63
MAZE 4	SUBJECT 1	60.54	60.19	76.92	64.92
	SUBJECT 2	77.96	56.22	36.57	93.36
	SUBJECT 3	49.59	61.73	67.24	58.76
	SUBJECT 4	82.09	79.48	79.71	82.46
MAZE 5	SUBJECT 1	61.24	52.50	70.48	69.26
	SUBJECT 2	56.64	66.81	76.65	76.74
	SUBJECT 3	47.42	30.64	25.96	30.65
	SUBJECT 4	79.95	65.05	80.34	47.75
MAZE 6	SUBJECT 1	78.79	76.47	79.39	71.63
	SUBJECT 2	93.19	84.28	93.36	75.91
	SUBJECT 3	98.57	62.79	63.51	29.94
	SUBJECT 4	63.29	63.15	58.02	56.18
MAZE 7	SUBJECT 1	78.31	55.20	57.27	77.50
	SUBJECT 2	67.01	39.91	59.91	22.27
	SUBJECT 3	51.07	63.66	70.15	53.14
	SUBJECT 4	73.04	63.73	73.14	69.89
MAZE 8	SUBJECT 1	62.14	51.98	89.94	48.15
	SUBJECT 2	15.27	81.46	58.60	49.62
	SUBJECT 3	38.29	46.09	39.76	5.93
	SUBJECT 4	40.18	42.75	84.67	45.69

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SECTION 6.0

CONCLUSIONS

There are two important conclusions to be drawn from these results. First, it is evident that increased +Gz stress produced a significant increase in perceived workload. Second, the discrepancy between the performance and workload measures suggests that the demand imposed by the maze-solving task did not force subjects to work at capacity, and allowed them sufficient processing resources to compensate for the effects of the +Gz stress.

SECTION 5.0

DISCUSSION

Performance on the maze-solving task was not affected by +Gz stress, although subjective ratings of workload were. The level of demand presented by the maze-solving task appears to have been such that subjects were able to accommodate the additional demand imposed by acceleration stress, and maintain their performance. Results of this study show that SWAT ratings may precede performance decrements, and be important "leading indicators" of task performance degradation. The increase in SWAT ratings was linear with +Gz, and there was some indication that the increase may become quadratic at higher acceleration levels.

The offset rule for acceleration was modified after data from the first two subjects had been obtained, because it was felt that the small improvement in performance from +3 Gz to +5 Gz was due to the variable duration of acceleration. The hypothesis was that when subjects were exposed to the higher +Gz level and the duration of the acceleration depended on how quickly they solved the maze, their motivation to complete it as quickly as possible increased. However, with the second offset rule for acceleration (a fixed duration of 1 min.) the same small improvement in performance at +5 Gz was obtained. This increase in score, if it is repeatable, may be due to overall motivational factors unrelated to the rule for acceleration offset.

The comparison between trials in which the solution paths were not shown versus those in which they were demonstrates that maze-solving is primarily a cognitive rather than a motor-response task. This is apparent from both the performance scores and the subjective workload ratings.

+Gz stress had a significant effect on the SWAT ratings obtained ($F=12.41$, $df=3,6$, $p<.01$). Even though the per⁻ormance measure did not detect a difference among +Gz levels, this subjective measure showed a dramatic increase in workload as a function of increased +Gz. The only other significant effects on SWAT ratings were due to a main effect for differences among mazes ($F=2.65$, $df=7,14$, $p<.10$), a main effect for differences among subjects ($F=21.96$, $df=2,14$, $p<.01$), and an interaction effect of +Gz with subject ($F=5.43$, $df=6,41$, $p<.01$). As for the maze-solving scores, the main effects of maze and subject were expected. The interaction of +Gz with subject was due to one subject who gave relatively low workload ratings to conditions under acceleration; the remaining three subjects were quite consistent with each other.

Linear and quadratic functions of +Gz level were used to fit the SWAT ratings obtained. The linear effect was statistically significant ($F=31.5$, $df=1,9$, $p<.01$) and the quadratic effect was not ($F=2.45$, $df=1,9$, $p<.10$). There is, however, some suggestion that the SWAT rating for +6 Gz is slightly higher than a linear trend would predict, so there may be a quadratic relationship for higher +Gz levels.

Analysis of variance was also used to assess the effects of the independent variables for conditions in which the solution path was shown, during the last session of Phase III. A simplified model was used for these hypothesis tests, since all mazes were not observed at all levels of +Gz. Only the main effects of +Gz, maze, and subject were tested, and the error term used was the residual. The effect of offset rule was not included, since it seemed unlikely to have any impact on trials in which the mazes were solved very quickly, as these were.

The maze-solving score was affected moderately by all three of these factors. The largest difference was among subjects ($F=30.3$, $df=3,18$, $p<.05$). Differences among +Gz levels were smaller ($F=17.1$, $df=3,18$, $p<.10$), as were differences among mazes ($F=14.5$, $df=7,18$, $p<.10$). Differences among subjects and mazes were expected. The differences among +Gz levels were small; a decrement in average score from 94.4 at +1.5 and 3 Gz to 92.4 at +5 and 6 Gz. This change may reflect the extent of additional physical difficulty in performing the maze-solving task at the higher levels of +Cz. The maze-solving scores obtained with the solution paths shown were much higher than those obtained when they were not, indicating that maze-solving is primarily a cognitive rather than a motor response task.

SWAT scores were affected by both +Gz levels ($F=12.15$, $df=3,18$, $p<.01$) and mean differences among subjects ($F=4.31$, $df=3,18$, $p<.05$). As can be seen in Figure 5, the changes in SWAT scores as a function of +Gz level paralleled the changes found for conditions in which the solution path was not shown. The mean difference in SWAT scores obtained when a solution path was shown versus when it was not was an increase of approximately 14 points on the rating scale, regardless of +Gz level. This indicates that the increase in subjective workload imposed by the cognitive aspects of the maze-solving task was independent of the amount of +Gz stress.

SECTION 4.0

RESULTS

Figures 4 and 5 summarize the effect of +Gz stress on the maze-solving scores and the SWAT ratings respectively. Separate results are shown for conditions in which the solution paths were not shown (the first part of Phase III) versus those in which they were. Each figure shows the means by +Gz level, averaged across mazes, subjects and acceleration offset rule. The confidence intervals shown are based on the error terms obtained from the analyses of variance.

Univariate analysis of variance (ANOVA) was used to test the effects of the independent variables on maze-solving scores and on SWAT ratings obtained during trials in which the solution paths were not shown. The factors used and their levels were as follows:

1. +Gz stress (+1.5, 3, 5, or 6 Gz).
2. Maze used (eight different ones).
3. Offset rule for acceleration (variable length duration with a maximum of 2 min, or fixed length duration of 1 min at +Gz).
4. Subjects nested within offset rule.

The factors of maze and subject were treated as random factors, and the other two were fixed. All main effects and interactions of the first three factors were tested. For some of these hypotheses, an exact F-test was not available because of the constraints imposed by the presence of random factors; the procedure outlined by Scheffe (16) for approximate F-tests was used for these cases.

The distribution of residuals in the analyses of variance were found to be approximately normal, with the exception of one unusually small value for one of the SWAT ratings. This observation was omitted from the formal analysis.

The data obtained from the first part of Phase III are summarized in Tables 1 and 2, for the maze-solving scores and the SWAT ratings respectively. The results of the analysis of variance for these two measures are shown in Tables 3 and 4. The latter two tables also show results for the analysis performed on data obtained during the last session of Phase III, when the solution paths were shown.

Task performance as measured by the maze-solving score was not affected by the level of +Gz stress ($F=1.94$, $df=3,6$, $p<.10$). The only significant differences in maze-solving scores were attributable to a main effect for the differences among mazes ($F=4.35$, $df=7,14$, $p<.01$), a main effect for the differences among subjects ($F=3.48$, $df=2,14$, $p<.10$), and an interaction effect of maze and offset rule ($F=3.13$, $df=7,14$, $p<.05$). The main effects of subject and maze were expected. The interaction effect for maze by offset rule was somewhat anomalous. Of the eight mazes, higher scores were obtained on four of them with one offset rule, and on the other four with the other offset rule. Which offset rule yielded the higher score did not appear to be related to performance or structural characteristics of individual mazes.

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and mean differences among subjects ($F=4.31$, $df=3,18$, $p<.05$). As can be seen in Figure 5, the changes in SWAT scores as a function of +Gz level paralleled the changes found for conditions in which the solution path was not shown. The mean difference in SWAT scores obtained when a solution path was shown versus when it was not was an increase of approximately 14 points on the rating scale, regardless of +Gz level. This indicates that the increase in subjective workload imposed by the cognitive aspects of the maze-solving task was independent of the amount of +Gz stress.

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15. Eggemeier, F.T. et al. The effects of variations in task loading on subjective workload rating scales. IEEE Nat Aerosp & Elect Conf, NAECON Proceedings, 1983.

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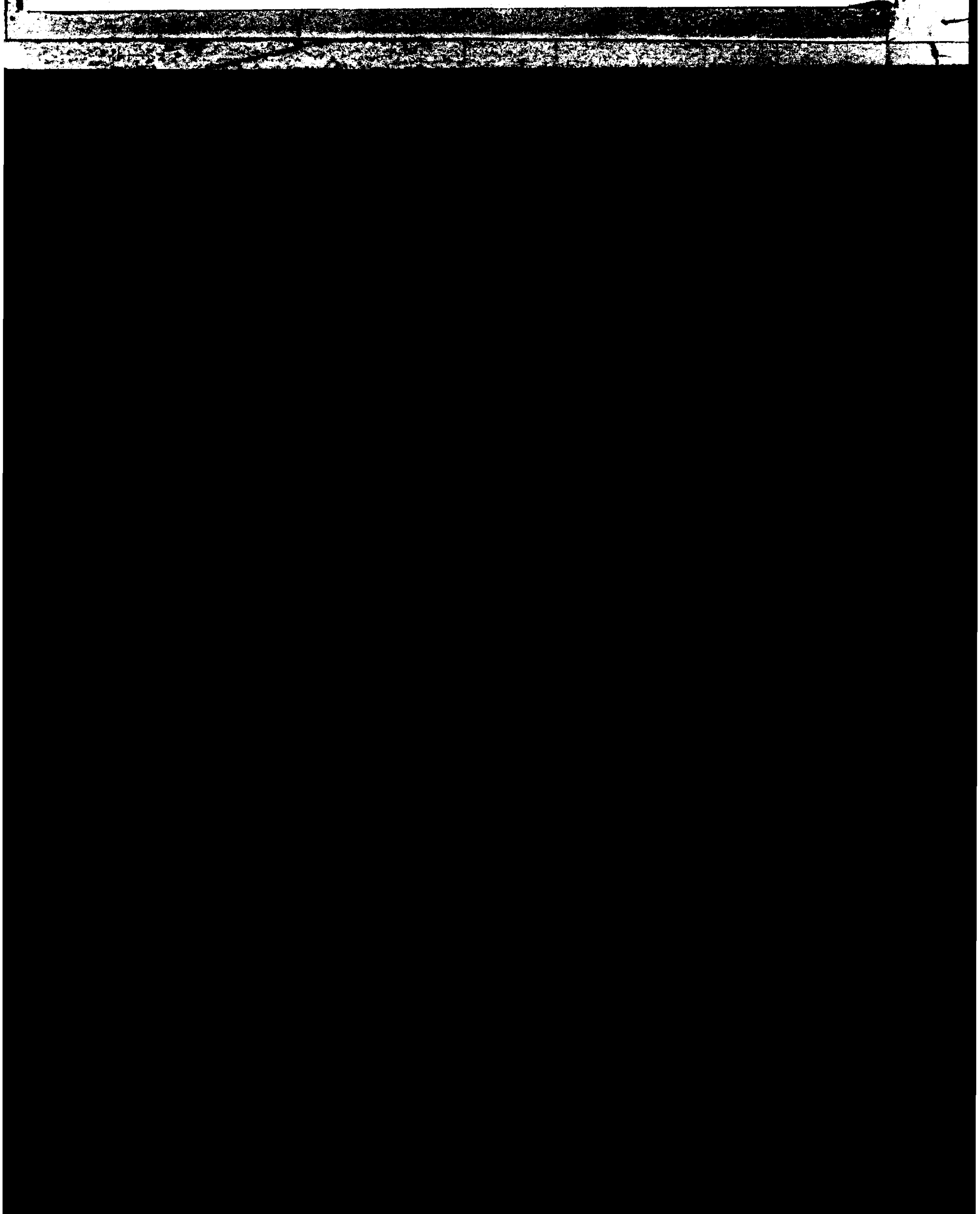
MAZE 8	SUBJECT 1	62.14	51.98	89.94	48.15
	SUBJECT 2	15.27	81.46	58.60	49.62
	SUBJECT 3	38.29	46.09	39.76	5.93
	SUBJECT 4	40.18	42.75	84.67	45.69

MAZE 8	SUBJECT 1	11.83	11.83	1.70	13.53
	SUBJECT 2	58.01	0.0	58.01	95.70
	SUBJECT 3	30.10	30.10	59.66	91.04
	SUBJECT 4	29.79	39.33	41.16	91.04

Fig. 1 TYP



PSYCHOL
STRESS

TIMI
LOA

Fig. 3. TYPICAL STRIP CHART RECORDINGS FROM MAZE EXPERIMENT, 6 G RUN

* U.S. GOVERNMENT PRINTING OFFICE: [illegible]